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VARIATIONS OF TEXTURE IN CERTAIN TERTIARY IGNEOUS ROCKS OF THE GREAT BASIN.[1]

INTRODUCTION.

DURING the field work of the writer in the Great Basin, in 1899, he found in a number of localities, chiefly near the edge of the Sierras, cases of what seemed at first extraordinary transitions or intimate alternations of texture in the Tertiary igneous rocks, which are for the most part extrusive. Microscopic and comparative examination in the office corroborated the field conclusions and showed also that the transitions were not as abrupt as they seemed at first, but were more gradual ; and the study of the conditions of crystallization which may be inferred from the structure of the different varieties shows that similar conditions must exist in many other places and similar transitions may be looked for. It is true that there are in that portion of the Great Basin especially under consideration (namely, the district lying within fifty miles of Carson) exceptionally favorable circumstances for the exposure of both the surface portions and the originally deeply buried portions of lavas. The region is an arid one, and therefore the general erosion is slight ; nevertheless, waters derived from the moister Sierras reach out into this region in the form of streams, and have accomplished much special or basal[2] erosion. There are also a number of lakes, which in former times were much more extensive, and probably existed in one stage or another since early Tertiary times ; and the basal erosion of these lakes has probably been considerable.

Some of the special localities where the observations were made will now be described in detail.

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[1] Published by permission of the director of the United States Geological Survey.

[2] *I. e.*, Erosion which works at the base of topographic features, undercutting them.

ANDESITIC ROCKS.

MASON'S BUTTE.

Field description.—Mason's Butte lies close to Walker River, in Mason Valley, about four miles due south from Wabuska. It is thus situated midway between the northern end of the Walker River range and the northern end of the Smith Valley and Pinenut ranges. The rocks of the butte are related to those of all these ranges, as will be shown later. The butte itself is about a mile and a half long in a northeasterly direction, and about half a mile wide. It presents from a little distance the appearance of typical volcanic rock, being distinctly thinly bedded, with red and gray zones. On the western face of the butte is a scarp two or three hundred feet high, and from here easterly there are a series of saw teeth, caused by the unequal erosion of the bands of which it is composed; then the butte sinks gradually into the plain again. The bands of igneous rock dip easterly 15° at the western end of the butte, and the dip increases to the east, so that on the eastern end they dip 30°. Here they are locally reversed and dip west, probably from movement subsequent to the eruption, which movement is also evidenced by shearing. The beds strike parallel with the longest extension of the butte (see Fig. 1).

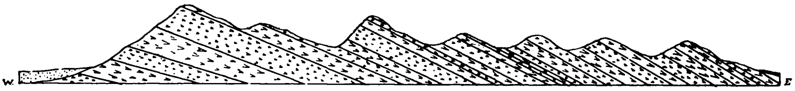

FIG. 1.—Cross section of Mason Butte, showing alternations of course and fine textured dioritic beds. Drawn to scale. Scale, 1 inch=850 feet.

Upon examination, the rocks are found to be diorite and andesite in alternating conformable layers. Fourteen different layers of diorite were found in the half-mile section, with layers of diorite porphyry and andesite between. From a structural point of view, all these rocks grade into one another. Sometimes the gradation may be actually seen in a single bed; for example, a highly porphyritic andesite, which in the field was taken for a diorite porphyry, was found to change gradually into a coarsely crystalline diorite; but generally the beds are separate. The coarse-grained rock contains some dark inclusions, which appear to be like the finer-grained rocks. The diorite is also associated with alaskite[1] which occurs in many large segregated masses irregularly distributed, and with a few quartz veins, also segregational. The alaskite and quartz veins are found only in the diorite; never in the fine-grained rocks. At the eastern end of the butte, also associated with the diorite, are considerable masses of hornblendite which grade into normal diorite.

Although a careful search was made, no intrusive phenomena showing that the andesites are intrusive into the interbedded diorites, or vice versa, were found. Although the whole butte is of rugged rock and entirely free from any vegetation sufficient to obscure exposures, yet the succession of the different beds is as normal and regular as in the case of sediments. The andesites are evidently similar to the Tertiary andesites which occur plentifully in the whole region round about. The conclusion reached in the field, therefore, was that Mason's Butte represents the roots of old volcanic flows, that the apparent bedding is a flow structure on a large scale, and that the coarse-grained and fine-grained rocks, the diorites and andesites, are different forms of crystallization from a single magma. Some of the fine-grained rocks are separate layers from the coarse-grained ones, while some are simply variations in them. The diorite naturally incloses portions of an earlier formed crust, which is identical with the finer-grained beds.

Microscopic evidence.—The structure and composition of typical specimens from this butte will now be described:

Hornblende-biotite-quartz-diorite[2] (117 N.).—This rock in the hand specimen is medium coarse granular and rather dark, on account of a liberal percentage of ferromagnesian minerals. It has the appearance of a typical granular rock. Under the microscope the structure is coarse. The largest grains are as much as 8^{mm} in diameter, and these grains, which have hypidiomorphic or idiomorphic outlines, are closely intergrown. Filling the spaces left by the intergrowth of these larger grains is a somewhat scanty mesostasis, composed of grains averaging about 1^{mm} in diameter. The minerals of the larger and the smaller grains are the same, consisting of feldspar, which is greatly in excess, and quartz, green hornblende, and biotite. The quartz is distinctly subordinate in amount to the feldspar. The feldspars were tested by the Fouqué method and gave, on sections perpendicular to both the positive and the negative bisectrices, the extinction angles for oligoclase.

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[1] See *Am. Geol.*, April, 1900, p. 230. *Alaskite* is proposed as a general name for rocks consisting of quartz and alkali feldspars without essential ferromagnesian constituents.

[2] These numbers refer to the specimens in the writer's collection, and are given for the purposes of subsequent identification.

Hornblende-biotite-quartz-diorite (123 N.).—This does not differ in the hand specimen to any noticeable extent from 117 N. Under the microscope also the two are essentially alike, but with a slight difference. In 123 N. the larger crystals are more abundant, so that the structure at first sight appears to be coarse allotriomorphic granular. On closer analysis the section is seen to be made up of more or less idiomorphic crystals of feldspar, green hornblende, and biotite, closely packed together, with the spaces between filled with a scanty mesostasis of quartz, feldspar, hornblende, and biotite, these grains being of all sizes, commencing with the size of the idiomorphic grains just described. In this section, as in 117 N., the quartz is a subordinate essential. The feldspar, tested twice by the Fouqué method, gives the angles for andesine-oligoclase.

Hornblende-andesite (116 N.).—This is a porphyritic rock with an abundant, greenish groundmass, and is entirely similar in appearance to the hornblende-andesites of the Pinenut range, just west of the butte. Under the microscope the groundmass is found to be holocrystalline and microgranular, consisting chiefly of allotriomorphic feldspar and hornblende. The phenocrysts reach a diameter of about 2.75^{mm}, and consist of feldspar and green hornblende. The feldspars, when tested, gave twice the extinction angles of andesine. In this section the phenocrysts are less in amount than the groundmass.

Hornblende-andesite (118 N.).—In the hand specimen this has the appearance of a diorite closely verging upon diorite porphyry. Under the microscope, however, there is found to be, between the closely packed phenocrysts, a micro-granular groundmass, slightly finer grained than that of 116 N. It consists chiefly of feldspar with some hornblende. The phenocrysts also are chiefly feldspar, with subordinate hornblende, which is largely altered to epidote. Determinations of the feldspar show that it is oligoclase. The larger phenocrysts have an average diameter of about 2^{mm}.

Hornblende-quartz-andesite (121 N.).—This rock is similar in appearance to 118 N. It has also a fine holocrystalline granular groundmass, showing no fluxional arrangement and composed of feldspar and quartz. The phenocrysts have a maximum diameter of about 3^{mm}, and consist of feldspar, green hornblende, and subordinate quartz, the last named in large rounded or corroded crystals. The hornblende is largely altered to epidote. The feldspar, tested twice by the Fouqué method, shows the extinction angles of andesine and andesine-oligoclase.

Hornblende-quartz-andesite (120 N.).—This rock in the hand specimen is dense, greenish and fine grained, having a trap-like appearance, with small phenocrysts in an aphanitic groundmass. Under the microscope the rock is seen to be much like those just described. The groundmass is fine holocrystalline, consisting of lath-shaped feldspars and hornblende, with subordinate quartz and some pyrite and siderite. There is a slight fluxional arrangement. The phenocrysts belong to a distinct generation from the groundmass (*i. e.*, there are no transitions) and consist of feldspar, pale green hornblende, and a single large grain of corroded quartz. The phenocrysts reach a diameter of 2^{mm}. The hornblende is largely altered to calcite, chlorite, and epidote.

Hornblende-andesite (119 N.).—This is from the same bed as 120 N., and is simply a variation from it. In appearance it is somewhat different, on account of the more abundant conspicuous feldspar phenocrysts, which are, however, very small, so that the rock resembles a miniature of 121 N., reduced three or four times. Under the microscope the groundmass is seen to have been originally glassy, but now is devitrified, and has a cryptocrystalline structure, The phenocrysts attain a diameter of about 1^{mm}, and consist of feldspar and hornblende. The feldspar, upon optical examination, proves to be oligoclase. The hornblende is mostly altered to calcite and chlorite.

Alaskite (114 N.).—This in the hand specimen is a typical, rather fine-grained, dense rock. Under the microscope the structure is hypidiomorphic granular. The grains average 1^{mm} in diameter, and consist of quartz, orthoclase, and microcline in somewhat equal proportions. The only dark minerals present are a few grains of chlorite and pyrite.

Hornblendite (124 N.).—This is a coarse-grained rock, typical of its kind, and also consists of green hornblende, with blotches of epidote. Under the microscope the structure is seen to be allotriomorphic. No other minerals are present save those mentioned, and the epidote is secondary to the hornblende. In the section studied the grains average about 3^{mm} in diameter.

Analysis of structure.—The series of rocks just described, from 117 N. to 119 N., inclusive, shows a transition, which has at one end a typical coarse granular rock and at the other a porphyritic rock with a glassy groundmass. In the intermediate stages the phenocrysts increase in numbers and somewhat in size, while the groundmass shrinks in volume and becomes also coarser. In 123 N., which is a typical granular rock only slightly removed from 117 N., these phenocrysts have increased until they nearly fill the rock, while the small portion of groundmass which remains has coarsened so that the grains are a millimeter in diameter; thus the rock at first sight appears a typical allotriomorphic granular rock, from which it is moreover not far removed.

The very slight variations of structure between any two adjacent members of this transition series shows that the differences in condition which brought about the separation of the coarse-grained from the fine-grained rocks were relatively small. These differences are plainly longer cooling periods (and hence longer crystallization intervals) in some portions of the rock, as compared with others. The coarse granular rocks, judging from their almost complete and uniform crystallization, have crystallized entirely in their present position; the segregation from them of alaskite on the one hand, and hornblendite on the other, is additional evidence of this. The porphyritic forms, however, show generally two distinct generations, and this, with the fact that some of the phenocrysts of the first generation, especially the quartz, show corrosion and resorbtion, indicates a change of conditions; also the slight fluxional arrangement, sometimes observed, shows at least local movement. Yet the contemporaneity of the fine-grained porphyritic rocks with the granular forms, shows that the crystallization break registered by the former did not arise from any important change of position.

Composition of rocks. — The general mineral composition of rocks of all structures (leaving out the alaskite and hornblendite, which are plainly segregation products from the hornblende quartz-diorite), is the same, being a hornblende-quartz-diorite or quartz-andesite. In the andesites the quartz, where present, was plainly in process of resorbtion by the groundmass at the time of solidification, so that it is probable (from the fact the hornblende andesites and the hornblende-quartz-andesites often occur as variations of a single bed) that in those andesites which do not show free quartz the composition is the same as where they do, the quartz belonging to the first period of crystallization having been entirely resorbed.

Analyses of the rocks are as follows (analyst, Dr. H. N. Stokes):

No. 1, No. 117 N. Hornblende-biotite-quartz-diorite		No. 2, No. 120 N. Hornblende-quartz-andesite	
SiO_2	60.25	SiO_2	53.37
Al_2O_3	17.90	Al_2O_3	16.57
Fe_2O_3	3.08	Fe_2O_3	3.84
FeO	2.44	FeO	2.45
MgO	2.44	MgO	5.79
CaO	5.57	CaO	6.30
Na_2O	4.29	Na_2O	3.40
K_2O	1.89	K_2O	2.55
H_2O+	.20	H_2O+	.39
H_2O	1.24	H_2O	2.33
TiO_2	.65	TiO_2	.86
CO_2	none	CO_2	1.61
P_2O_5	.25	P_2O_5	.29
MnO	.06	MnO	.08
SrO	.07	SrO	trace
	100.33		99.83

In No. 1 the ratio of $Na_2O + K_2O : CaO = 1 : 1.1$. In No. 2 the same ratio is 1 : 1.13. These ratios are calculated from the quotient figures obtained by dividing the percentages of each by the molecular weights. Similarly in No. 1 the ratio of $K_2O : CaO$ is 1 : 4.95. In No. 2 the same ratio is 1 : 4.18.

No. 2 contains less quartz and more hornblende than No. 1, hence the decrease in silica and the increase in magnesia; otherwise the two rocks are the same.

Correlation of rocks.—As before stated, just west of Mason's Butte lies the northern end of the Smith Valley and Pinenut ranges. On crossing from Waubuska through Churchill Canyon, andesites were found which were recognized in the field as similar to those in the butte. The bedding of these rocks is nearly horizontal. They are fine-grained hornblende-andesites, often with fine holocrystalline groundmass; occasionally they vary to fine-grained diorite porphry. In higher portions of the mountains (these relatively coarse-grained lavas are exposed in the lowest cuts) the lavas are dacites and pyroxene andesites.

Andesites form the main mass of the Pinenut range at its northern end, which is separated from the Washoe district at the southern end of the Virginia range by a comparatively narrow valley. The lavas of one range are evidently continuous with those of the other.[1] In the Washoe district have been found eruptions of hornblende-mica-andesite and quartz-andesite or dacite, corresponding exactly to that at Mason Butte. At Washoe, also, the andesite becomes, under favorable conditions, coarsely crystalline, and Messrs. Hague and Iddings[2] have noted that upon this complete crystallization quartz separates out, producing a mica-quartz-diorite.

RHYOLITIC ROCKS.

TRANSITIONS IN TEXTURE OF THE BASAL RHYOLITES OF THE PINENUT RANGE.

Field description.—The central core of the Pinenut range is made up of granitic rocks. These were examined in two localities: one southeast from Dayton, and one west from Wellington.

At the first mentioned locality, granitic rocks are exposed along an easterly facing scarp which is at the north end of Smith Valley. The rocks are all granular, so far as observed, but vary much in texture from fine to coarse; they are often porphyritic. They show a distinct banding, resembling at a distance rude stratification; this banding is due to a zonal arrangement of the rocks of different textures.

In the district west from Wellington, rhyolitie and granitic rocks are exposed in the spur just east from the Mountain House, and are of exceptional interest. Here, beneath the andesitic rocks which cover the mountain slopes, is found a highly indurated volcanic conglomerate and sandstone, apparently waterlaid, and consisting entirely of rhyolitic material. A short distance farther on, the rocks from which these detritals are derived were found in place. These original rocks show great variations, passing from a fine-grained, almost aphanitic, rhyolite, to coarse siliceous granite and alaskite. The numberless variations are within a few feet of one another and are arranged in bands, recalling immediately the similar phenomenon in the andesitic rocks of Mason Butte. In the case of the rhyolitic rocks also there is no sign of intrusion of one into another, nor in general does there appear to be any marked gradations between the different bands at contact, the boundaries between them being fairly distinct.

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[1] See "The Succession and Relation of Tertiary Igneous Rocks in the Great Basin Region," JOUR. GEOL., Vol. VIII, p. 621.

[2] Bull. 17, U. S. Geol. Surv.

It is clear in the field that the variations are chiefly textural and that the composition of all the varieties is nearly the same — that of siliceous granite or rhyolite.

In this case again, we have rocks which appear to represent the roots of old volcanics, being intermediate between completely massive plutonic igneous rocks and superficial fine-grained volcanics. They must have suffered a flowage resulting in the formation of this peculiar streaky structure, while the great variations in texture in the different bands show crystallization at points still far removed from the surface.

Of the different rock varieties in the locality west from Wellington the following will be briefly described.

Biotite-rhyolite (164 N^a.).—Structure porphyritic; groundmass cryptocrystalline, probably devitrified glass. The phenocrysts are of all sizes, the larger ones grading down to those which vanish in the groundmass. They are of feldspar, quartz, and biotite, the latter decomposed. The feldspar was determined to be largely albite and oligoclase-albite, although there is some orthoclase, The largest phenocryst of feldspar measures 2¾^{mm} in diameter; the largest one of the quartz, 1½^{mm}. The rock contains angular fragments of finer grain. Some of these seem to be devitrified rhyolitic glass, while others are fragments of more basic lava, probably andesite — these latter show small lath-shaped feldspar phenocrysts in a glassy semi-devitrified groundmass.

Biotite-rhyolite (165 N^a.).—In this specimen the groundmass becomes slightly coarser than in the preceding specimen and is very fine microgranular. It also becomes more scant than in

164 N^a, on account of the multiplication of phenocrysts, which show the same great variety in point of size as the rock just described. The same angular fragments of more basic lava also occur. The phenocrysts are quartz, orthoclase, and a striated feldspar; the latter tested twice by the Fouqué method proves to be albite. The orthoclase was optically determined as such.

Rhoylite (162 N^a.).—In this rock the groundmass is fine holocrystalline, coarse enough to enable one to distinguish the mosaic of quartz and feldspar. This groundmass contains the same fragments of more basic lava that have already been described, and also encloses broken phenocrysts of mostly unstriated feldspar.

Granite-porphyry, fine-grained (169 N.).—In this rock the groundmass is fine granular, sometimes granophyric, and conrists chiefly of quartz and orthoclase. The phenocrysts are abundant and consist of quartz and feldspar, with chlorite and epidote which are derived from the decomposition of ferromagnesian minerals. The feldspar phenocrysts are partly orthoclase and partly a striated feldspar, which, determined by the Foqué method, proves to be oligoclase-albite.

Biotite-granite, medium-grained (171 N.).—In this rock the grains are of two distincts sizes, one many times larger than the other. The larger grains have a tendency to idiomorphism, the smaller grains to allotriomorphism. The smaller grains are included between the interlocking larger ones and may be considered as forming an overgrown groundmass, partly crowded out by the multiplication and joining of phenocrysts, which are represented by the larger grains. The minerals of the rock are quartz, feldspar, biotite, and magnetite. The feldspar is almost entirely orthoclase, with some microcline and albite.

Granite, coarse (175 N.).—The structure of this rock is like that of the preceding, only coarser. It contains many perfect idiomorphic crystals of feldspar, often touching and almost interlocking, and smaller crystals of bleaching biotite and ragged pale green hornblende, the last perhaps secondary. These minerals are in general cemented by a mesostasis of coarse allotriomorphic quartz, which often includes or is intergrown with, in poikilitic fashion, smaller crystals of feldspar, pale green hornblende, and sphene. The feldspar included in the quartz sinks to very small dimensions, whereas the ordinary feldspar grain is very large. The structure may be regarded as the coarsening of the porphyritic structure, or at least closely related to it by reason of the two generations. The large feldspar crystals are partly orthoclase, but are chiefly finely striated. Optical determinations of the striated crystals show microcline-anorthoclase and albite.

Granite, coarse (172 N.).—This rock is almost entirely like 175 N, and has a good deal of the peculiar structure of this rock, but in general is more hypidiomorphic granular or truly granitic.

Analysis of the structures of the granite-rhyolites.—The analysis of the structure of the granites and rhyolites just described helps toward a better understanding of their relation.

164 N (a). Here are phenocrysts of all sizes, gradually shrinking in size to the glassy (sometimes slightly devitrified) groundmass; *i. e.*, the crystallization, instead of belonging to one or two distinct generations, represents many generations, not separable from one another. This is a proof of gradual and equable hardening. It shows that the viscosity increased very slowly and regularly to the point of final complete solidification, the newer crystals having progressively smaller fields of crystallization.

165 N(a). This is like 164 N(a) except that the groundmass diminishes, on account of multiplication of phenocrysts. This marks a longer cooling period than 164 N(a), so long as almost to permit of total crystallization as relatively large crystals.

162 N(a). In this section the feldspar phenocrysts are not connected by gradual transitions with the groundmass, which is slightly coarser than that of 165 N(a) and is much more abundant. We have, therefore, two distinct generations of crystallization, and this, together with the frequently broken character

of the phenocrysts, indicates a break in the crystallization, evidently resultant from a movement of the solidifying mass. The order of events in this section was, therefore, (1) comparatively slow crystallization of feldspar; (2) flowage, producing a change of conditions; (3) medium rapid cooling, bringing about the uniform moderately fine crystallization of the rest of the rock.

169 N. Here the line between the abundant phenocrysts and the fine-grained groundmass is, in general, distinct, for although there are transitions between the two they are not so abundant as in rocks like 164 N(a) and 165 N(a). This connotes a shorter period of first crystallization (when the phenocrysts were formed) than does 165 N(a), then a more rapid cooling than 165 N(a) to a certain point, then a slower rate of crystallization, permitting the formation of the uniform fine granular structure.

171 N. The structure of this connotes a long period of slight viscosity, during which the crystals of quartz and feldspar could grow until they touched and sometimes interlocked. The difference in size between these crystals and the grains of the groundmass or mesostasis which fills the space between them, implies a slight break or change of conditions, after which was again a comparatively slow uniform crystallization of the rest of the rock, producing an even allotriomorphic granular structure. There are then two distinct generations of crystals. The resulting structure is entirely similar to the ophitic structure of diabases, save that in these siliceous feldspars the forms are not so elongated, and so the structure is not so striking. The structure of this specimen, however, differs from the typical granitic structure in the same way that a diabase differs in structure from a gabbro. A longer period for the first crystallization, reducing the mesostasis to a still smaller percentage, would give the aplitic structure, where the idiomorphic crystals are predominant and occupy the greater portion of the section.

175 N. This is like 171 N, but in general the mesostasis of comparatively small grains is wanting, being replaced by a filling of coarse allotriomorphic quartz. In this case the conditions of crystallization have evidently been gradual throughout. The

rock crystallized slowly under conditions of slight viscosity. After the exhaustion of the feldspathic material residual quartz crystallized in the remaining spaces.

Tabulation.—The following table shows the gradation from fine-grained rhyolite to granite:

Specimen No.	Character of groundmass.
164 N (a)	Glassy.
165 N (a)	Cryptocrystalline.
162 N (a)	Finely microgranular.
169 N	Microgranular; micropegmatic.
171 N	Granular; grains average $.5^{mm}$ diameter.
172 N	Granular; grains average $.5^{mm}$ diameter.
175 N	Large quartz grains, average 2.25^{mm}.

Analyses.—The following are analyses of the two fairly typical specimens as above described (analyst, Dr. H. N. Stokes):

(1) 168 N. Biotite rhyolite. Like 165 N (a).		(2) 172 N. Siliceous granite.	
SiO_2	71.49	SiO_2	75.09
Al_2O_3	15.06	Al_2O_3	13.51
Fe_2O_3	1.51	Fe_2O_3	1.13
FeO	.88	FeO	.08
MgO	.35	MgO	.18
CaO	1.54	CaO	.91
Na_2O	4.19	Na_2O	3.58
K_2O	3.39	K_2O	4.71
H_2O-	.16	H_2O-	.17
H_2O+	.88	H_2O+	.25
TiO_2	.20	TiO_2	.22
CO_2	none	Co_2	none
P_2O_5	.08	P_2O_5	.04
MnO	trace	MnO	trace
SrO	trace	SrO	trace
	99.73		99.87

It will be seen that No 2 is slightly more siliceous than No. 1; nevertheless the two rocks are intimately related. In No. 1 the relation of $K_2O + Na_2O : CaO = 1 : .26$. In No. 2 the same ratio equals $1 : .15$. Similarly, in No. 1 the relation of $K_2O : CaO = 1 : .75$. In No. 2 the same ratio equals $1 : .32$.

Conclusions.—Many of the bands in this granite-rhyolite series show by their structure that they have undergone no break in crystallization from beginning to end. The rocks have evidently crystallized entirely in their present position, and the slow hardening which is ordinarily indicated shows that this point of consolidation was originally some distance from the surface.

In other specimens there have been slight breaks, bringing about two, three, or more generations of crystals which in the rocks near by are not distinguishable. These minor breaks were due to slight migrations of material in certain bands, which flowed slightly during the process of cooling, as is proved by the angular fragments of finer-grained lava which they contain and by the occasional broken condition of the phenocrysts.

As explanation of the difference in crystallization between the granular bands and the intercalated fine-grained ones, it must be remembered that those bands which were affected by flowage must have been at the time those possessing least viscosity and consequently those which were least crystallized. The final crystallization of these bands, therefore, took place at a later period than that of granular bands, at which period the rate of solidification was very likely more rapid. It is probable, moreover, that the movement of flowage brought on of itself a more rapid crystallization than if the rock had been undisturbed, and that thus the finer-grained groundmass orginated. The same suggestions hold good for the similar phenomena, already described at Mason Butte.[1]

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[1] In connection with the conclusion above arrived at, *i. e.*, that the phenocrysts of the rocks were formed practically in place, compare the papers by Professor Pirsson and Professor Crosby. (*Am. Jour. of Sci.*, Vol. VIII, April, 1899, p. 271, "On the Phenocrysts of Intrusive Igneous Rocks," and *American Geologist*, Vol. XXV, No. 5, May, 1900, "On the Origin of Phenocrysts and the Development of Porphyritic Texture in Igneous Rocks.")

Professor Pirsson argues that the phenocrysts of intrusive rocks are not necessarily intratelluric, and that there is no necessity of more than one period of crystallization even for porphyritic rocks. From the fact that contact zones are often without phenocrysts, while the rest of the rock contains them; that in a contemporaneous complex of dikes and sheets some may have phenocrysts while others do not; from observed cases where fluidal phenomena show that phenocrysts have developed after the flowage; from the arrangement of the crystals of the groundmass around some phenocrysts, showing that these crystals have been crowded and shoved during the growth of the larger crystals; and from the fact that many granites (which have generally been considered intratelluric) contain very large phenocrysts, Professor Pirsson

TRANSITIONS OF TEXTURE IN THE GRANITE-RHYOLITES OF THE QUINN CANYON RANGE.

Field description.—The Quinn Canyon range lies a long distance east of all the other localities which have been described, being almost due south from Eureka and nearly west of Pioche. The whole southern portion of the range is buried in rhyolitic flows.[1] The range was examined by the writer at its northern end, where the Paleozoic core of the mountains emerge from the volcanic covering. On the western side of the range, near the contact of the Paleozoics with the rhyolite, the stratified rocks are pierced by numerous great dikes, which vary from coarse to fine in texture. These dike rocks seem similar in composition, and sometimes in texture, to the rather massive rhyolite which forms the hills to the west of this locality.

Microscopic description.—A specimen of the main rhyolite examined under the microscope has the following characteristics:

Rhyolite (241 N.).—This rock has phenocrysts of all sizes,

reasons that phenocrysts are not necessarily of a distinct crystallization period as compared with the groundmass, but may in some cases be formed in place. Professor Pirsson advances the explanation that a comparatively rapid fall of temperature and decrease of hydration, resulting in a viscosity augmenting in an increasing ratio, may produce monogenetic phenocrysts (that is, phenocrysts which occur only in a single generation). Recurrent phenocrysts (that is, those occurring in more than one generation) he explains as due to mass action, believing that minerals which are present in very large quantity are especially active crystallizers.

Professor Crosby believes that no sudden changes of temperature, hydration, or pressure, are necessary for the formation of phenocrysts. He believes that in a gradually consolidating rock the crystallization first established may be brought to a close by the gradually increasing viscosity and that after passing this critical point new zones of crystallization will be established, of much smaller field, and at this point the groundmass begins and the phenocrysts end. If the rate of cooling is still slower, an allotriomorphic granular texture results, while if the rate is more rapid the texture may be glassy or nearly so.

The deductions of the writer, given above, agree with those of the authors cited in this, that phenocrysts may be formed in place. His observations, however, go to show that where cooling is strictly uniform there will be no distinct generations, but a gradual transition from phenocrysts to groundmass; whereas, if there are distinct generations, they are brought about by breaks in the conditions of consolidation, even though these breaks be comparatively slight.

[1] G. K. GILBERT, *Survey West of the 100th Meridian;* Vol. III, Geology, p. 122.

from 1½^{mm} in diameter grading down into groundmass, which is cryptocrystalline, probably a devitrified glass.

Two selected specimens of the dike rocks have the following characteristics:

Biotite-granite-porphyry, near rhyolite (243 N.).—Like 241 N, this rock has phenocrysts of all sizes, from 1½^{mm} in diameter down to the groundmass. There are, however, more phenocrysts in this rock than in the one just described. As in 241 N, the phenocrysts have no fluxional arrangements, but a divergent one. The groundmass is fine holocrystalline allotriomorphic ganular.

Biotite-granite (242 N.).—This rock consists of grains of all sizes from 6½^{mm} in diameter down to the very minutest dimensions. The smallest ones, which are very abundant, are about .02 to .03^{mm} in diameter. There is a tendency to idiomorphism throughout. The smaller sizes of crystals act as mesostasis for the larger ones, and these have a mesostasis of the still smaller ones. The essential minerals are quartz, othoclase, and biotite, with accessory hornblende, titanite, magnetite, and a little striated feldspar.

Analyses.—The chemical composition of these rocks is as follows (analyst, Dr. H. N. Stokes):

(1) No. 214 N, Siliceous Rhyolite.		(2) No. 242 N, Biotite Granite.	
SiO_2	74.67	SiO_2	71.48
Al_2O_3	13.25	Al_2O_3	13.00
Fe_2O_3	1.06	Fe_2O_3	1.25
FeO	.18	FeO	1.55
MgO	trace	MgO	.95
CaO	1.26	CaO	2.60
Na_2O	3.99	Na_2O	2.60
K_2O	4.62	K_2O	4.24
$H_2O -$	.18	$H_2O -$	.20
$H_2O +$	.22	$H_2O +$	1.24
TiO_2	.07	TiO_2	.43
CO_2	.79	CO_2	.30
P_2O_5	.06	P_2O_5	.09
S	trace	S	none
MnO	none	MnO	.09
BaO	none	BaO	.09
SrO	none		
	100.35		100.11

In No. 1 the relation $K_2O + Na_2O : CaO = 1 : .2$. In No. 2 the same relation equals 1 : .53. In the same way, in No. 1, $K_2O : CaO = 1 : .46$. In No. 2 the same ratio equals 1 : 1.

Conclusions.—In the field the evident relation of the dikes to the rhyolite led to the inference that they had been the feeders of the extrusive rock. Under the microscope the composition of the three rocks is found to be the same, and the structure shows variations indicating no great differences in the conditions of cooling. The structure is identical with that of certain specimens of rhyolite-granite just described from the Pinenut range, and therefore need not be analyzed again. Briefly, in all three it indicates complete crystallization in one place, with no interrupting movement. The period of consolidation for 241 N was comparatively short, that of 243 N somewhat longer, and that of 242 N markedly greater than 243 N.

ANALOGOUS CASES OF VARIATIONS OF TEXTURE IN OTHER PARTS OF THE GREAT BASIN.

In the Washoe district, Nevada, not far from the first locality decribed by the writer, Messrs. Hague and Iddings[1] found a gradual transition from pyroxene andesites with glassy groundmass to pyroxene-diabase with coarse granular structure. In the Sutro Tunnel they found coarsening of the crystallization as the tunnel nears the core of Mount Davidson, so that at one end the rock may be called andesite and at the other end diabase. They also discovered like transitions between andesite and granular diorites.

Similarly they found that the earlier hornblende-andesite passes into diorite, while the later hornblende-mica-andesite changes into mica-diorite in such a way that the two rocks are inseparable. They concluded that a dike of so-called diabase is a variation of the basalt, which was one of the latest extrusions.

In short, according to these writers, the coarse holocrystalline rocks of the Washoe district are chiefly Tertiary, and are partly extrusive and partly closely connected with extrusives of similar composition. Another interesting conclusion is that the change between the lava texture and the granitoid texture consists chiefly in the coarsening of the groundmass.

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[1] Bull. 17, U. S. Geol. Surv.

In 1899, Messrs. Tower and Smith described textural transitions in the Tintic range in Utah, which lies within the petrographic province of the Great Basin and is situated southward from Great Salt Lake.[1] In this district is found pyroxene andesite or perhaps more properly latite, which is an effusive rock and is closely associated with granular monzonite. There are all variations of texture between andesite with glassy groundmass to that with a holocrystalline groundmass; from this to closely similar rocks, also with holocrystalline groundmass, which are called monzonite porphyry; and from these through panidiomorphic granular phases to those of hypidiomorphic granular structure.

CONCLUSIONS.

In the Great Basin, particularly in Nevada, we have Tertiary extrusive rocks which show transitions from a granular structure with glassy groundmass. The different phases are often intimately associated, and structural analysis shows that the differences of crystallization which brought about these variations were slight, a relatively small decrease of the rate of cooling being sufficient to allow the formation of the holocrystalline instead of the porphyritic structure.

Transitions similar to those found in the Great Basin have been sparingly chronicled elsewhere. These appear to become rare in proportion as the rocks become siliceous. This is so because with a given relatively rapid rate of cooling a magma of basic composition will consolidate with a holocrystalline structure, while a siliceous magma will become fine-grained and porphyritic. We have accordingly many instances of holocrystalline diabases which are certainly extrusive, and of similar rocks in rather fresher condition (generally due to their being younger) which have been called dolerites. In the more siliceous rocks such textural transitions are rare in effusive bodies, but further down, at the roots of volcanoes, the conditions are such as to allow viscosity to increase with the same slowness that it does with a more rapid cooling rate in more basic rocks. Hence with increasing acidity we find the coarser grained varieties further removed from the surface. In general, however, it is plain that a granular rock is not necessarily a deep-seated one, in the formerly accepted sense of the word.

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[1] *Nineteenth Ann. Rept. U. S. Geol. Surv.*, p. 656.

Another conclusion which may be made from the foregoing studies is, that the more important structures are not peculiar to particular rocks. The porphyritic and the coarse granular allotriomorphic or hypidiomorphic structures are already recognized as characterizing all rocks, of whatever chemical composition. Also the aplitic structure, or that in which idiomorphic minerals (which are the same as the phenocrysts of the porphyries) form the greater bulk of the rock, has been recognized as universal by Rosenbusch, who has described it in granitic rocks and in all intermediate ones down to gabbros; thus his rock terms include syenite aplite and gabbro aplite. The ophitic structure has been generally supposed to be characteristic of diabases, and without question is here best exhibited, on account of the rate of solidification which the basic composition of a magma entails and also because the elongated forms of the basic feldspars make the structure prominent. The foregoing studies, however, show that this structure is intermediate between the porphyritic and the aplitic structures, representing a stage in crystallization when the idiomorphic crystals (or phenocrysts, as they are called in the porphyries) have multiplied and grown so that they interlock; and that like these other structures it may occur in any rock. In the granites it is not so striking as in more basic rocks, on account of the blunt form of the alkaline feldspars which form the first generation of crystals, but it is nevertheless present in some of the granites which have been studied. In diorites the ophitic structure has been occasionally described.[1]

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[1] ROSENBUSCH, *op. cit.*, p. 256; ZIRKEL, *Lehrbuch der Petrographie*, 2d ed., p. 483.

The writer, of course, interprets the term ophitic in its broader and not in its narrower sense, accepting it as meaning a structure where a network of interlocking, divergent, comparatively large feldspar crystals is filled in by grains of much smaller dimensions, whatever the nature of these grains may be. He does not interpret it as meaning that the mesostasis is necessarily augite. He finds grounds for this broader acceptation in the writings of Rosenbusch, Zirkel, and others. Rosenbusch applies the term ophitic[1] to diabases where the mesostasis is not augite, but an aggregate of primary quartz and feldspar.

Therefore, the glassy, fine porphyritic, coarse porphyritic, ophitic, aplitic and hypidiomorphic granular structures may occur in any rocks. They pass by gradual transitions into one another and are dependent upon relatively very slight differences in conditions of cooling. All may be formed without any marked migration of the consolidating rock.

These conclusions are important in considering rock classification, as showing that structure cannot be made the element of greatest importance. Granites, granite porphyries, granite aplites and rhyolites, for example, must not be separated, but put as closely together as possible, and the same is true of diabases, diabase porphyrites, diabase aplites, and basalts.

J. E. SPURR.

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[1] *Mikroskopische Physiographie*, 3d ed., p. 1117.